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The nature of the information stored in the perceptual learning of letter strings.

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THE NATURE OF THE INFORMATION STORED IN THE PERCEPTUAL LEARNING OF LETTER STRINGS

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Abstract

Pairs of 6-letter consonant strings which were repeated over sixteen sessions were matched SAME or DIFFERENT more rapidly than equivalent nonrepeated strings. Evidence is presented that this specific improvement in the matching RT for repeated strings is due neither to acoustic factors nor to an effect of familiarity on the comparison processes alone. This evidence, together with the finding that the effect persists over a seven-week period, suggests that stimulus familiarity can cause relatively permanent changes in perceptual encoding. Stored letter position information appears to be important in this perceptual learning, but information about visual features larger than single letters does not seem to be stored. These results are discussed in terms of their implications for the study of word perception.

INTRODUCTION

When you look at a word, what visual information enables you to recognize it? The simplest answer is that one first identifies the individual letters and then puts them together to identify the word. In 1885, Cattell tested this hypothesis by measuring the number of letters which could be reported from a tachistoscopic (10 msec) exposure. He found that Ss could report 3-4 unrelated letters, two unrelated short words, and four connected short words. In 1889, Erdmann & Dodge found that although no more than 7 unconnected letters could be reported from a 100 msec exposure, that familiar words containing as many as 20 letters could be correctly read. They concluded from this that information about the "general shape of the word" must be necessary for word recognition (Woodworth, 1938).

However, it has been suggested (e.g., James, 1890, p. 407) that memory may play a large role in the results of studies using the tachistoscopic report procedure. For instance, it may be that S can perceive 20 unrelated letters in 100 msec, but as he begins reporting the letters, the unreported letters begin to drop out of memory. But if the letters form a word, S may remember the word and reconstruct the forgotten letters from his knowledge of how the word is spelled. Also, evidence for the role of memory in the tachistoscopic report task has been provided by

Harcum's (1967) observation that the shape of the curve relating accuracy of tachistoscopic report to position of a letter in the string is very similar to the serial position curve found for the learning of nonsense syllables.

Furthermore, it could be that S sees an equal number of letters whether words or nonwords were briefly exposed, but that he reports more accurately from a display of words because he is able to guess a whole word after seeing only a few letters. Evidence for such an explanation has been offered by Newbigging (1961) who found that when Ss fail to recognize a briefly presented word, the probability of S guessing any given word is related to the frequency of occurrence of that word in written English. Presumably then, the probability that Ss would guess any particular novel string of letters is quite low. Thus, the possibility that the report of briefly exposed letter strings depends on memory factors and the familiarity of the responses raises some doubt about the early findings that words can be perceived more rapidly than unrelated strings of letters.

CONTROLLING FOR MEMORY AND RESPONSE FACTORS

Recently, the perceptual advantage of words over nonwords (the word-superiority effect, WSE) has been confirmed using several tasks which minimize the possible contribution of memory and response factors. In each of the tasks, the possibility that biases for emitting more frequent responses cause S's performance for words and nonwords to differ was ruled out by keeping the set of possible responses the same for words and nonwords, and by limiting the size of this response set to two.

Reicher (1969) used a probe recognition task to compare how accurately briefly presented words and nonwords could be perceived. He presented 4-letter strings followed very rapidly by a field containing a visual noise mask and a vertical pair of probe letters with 3 dashes to indicate the probed position. The purpose of the visual noise mask was to limit the time for extraction of visual information from the stimulus by interfering with any analogue representation of the stimulus which persists internally after the stimulus is removed (cf., Sperling, 1960). The S's task was to choose which of the two probe letters appeared in the indicated position of the briefly exposed word or nonword. To prevent guessing the probe letter of a word from the other letters seen, the alternatives were chosen so that when words were presented, both probe alternatives formed words with the nonprobed letters. Since S was required to make a choice on each trial, the percentage of correct choices was considered a measure of how rapidly visual information from the briefly presented letter string could be encoded. Reicher found that Ss could respond more accurately to letter strings which formed words than to letter strings which did not form words. This finding was confirmed using very similar tasks by Smith & Haviland (1972) and Baron & Thurston (1973).

Although the probe recognition task controls for response bias, it could be argued that memory is still a factor since the entire stimulus string must be remembered until a decision is reached on the probe alternatives. However, if the probe alternatives are presented before the stimulus display, then the correct response can be made independently of how long the stimulus letters remain in memory. Both Reicher (1969) and Baron & Thurston (1973) tested S using this precue condition, and both studies found that the perceptual advantage of words over nonwords persisted.

Krueger (1970a) compared the perception of words and nonwords by using a visual search task. S was first shown a target letter and then a display of five words or nonwords. His task was to search for the presence of the target letter in the display set and respond YES or NO as quickly and accurately as possible. The display set remained visable until S responded, thus insuring that memory need not influence the results. Krueger found that words were consistently scanned more rapidly than nonwords. Novik & Katz (1971), using a much smaller display size but otherwise similar procedure, confirmed Krueger's results.

The simultaneous matching task is a third method for studying the perception of letter strings in a way which minimizes the effects of memory and response factors. In this technique, S is presented with a pair of letter strings and must respond SAME if both letter strings contain the same letters in the same order, and DIFFERENT otherwise. Since S is instructed to respond as quickly and as accurately as possible, and since the letter strings remain visable until S makes his response, the reaction time (RT) for a SAME response is considered to be closely related to the time necessary to perceive the pair of letter strings.

Using the simultaneous matching technique, Eichelman (1970) found that 4- and 6-letter words could be matched more rapidly than random strings of letters. Egeth and Blecker (1971) varied the task so that each S made only one response; some Ss responded only when the pair of strings differed and others responded only when they were the same. Egeth & Blecker found a WSE for 3-letter stimuli, but only for the SAME responses. Using the two-response matching task, Schindler, Well, & Pollatsek (1973) found a WSE for 4- and 6-letter stimuli for both SAME and DIFFERENT responses, though the perceptual advantage of words was consistently smaller for the DIFFERENT responses.

Thus, these recent studies strongly suggest that it was not memory or response factors which were responsible for the early findings that letters in a word can be perceived more rapidly than an equal number of unrelated letters. These techniques were able to control for memory and response factors by introducing the necessity of some form of matching or comparison of visual information. However, this also introduced the possibility of a new artifact. Perception is commonly viewed as the forming of a stimulus-bound mental representation, or, as the process of encoding the stimulus. If it is the case that the advantage of words over nonwords in the probe-recognition, visual search, and simultaneous matching tasks is not due to differences in encoding, but only due to the more rapid comparison of the mental representation of a word with another or with a probe or target representation, then it could not properly be said that words are perceived more rapidly than unrelated letters.

ENCODING VERSUS COMPARISON STAGES

There are two general ways in which words and nonwords could be encoded using the same sequence of processes and yet have different rates of comparison. One would be if the encoded representation of a word consisted of fewer units than that of a nonword; then the comparison stage would be more rapid for words because there would be less to match. The other would be a direct effect of familiarity on the matching processes. For instance, comparison processes could be more rapid for stimulus representations which have been compared before.

One of the reasons the WSE has been the object of much study is that words and strings of unrelated letters have a similar number of visual features; words and nonwords are merely different orderings of the same letters. Therefore, if the encoding stage does not process a word differently than a nonword, how could the resulting representation consist of fewer units? One answer is that the letter strings which form words also correspond to verbal forms, and thus can be easily pronounced. Most strings of random letters, on the other hand, happen to be unpronounceable, except by listing the letter names. Whether the units used are syllables or phonemes, the acoustic representations of words will, in general, consist of fewer elements than those of nonword letter strings. Thus, if it is the acoustic representation of a letter string which is matched with another string or with a target/probe letter, then the task will be completed more rapidly for words than for nonwords. But in such a case, it would not be said that the word was perceived more rapidly.[1]

For all three of the tasks there is contradictory evidence as to whether Ss match acoustic representations of the words and nonwords. Mezrich (1973) replicated Reicher's (1969) probe recognition study, but added a 1.5 sec delay between the appearance of the visual noise mask and the presentation of the probe alternatives. During this delay, Ss were required to vocalize the stimulus. This vocalization enhanced the accuracy on single letter stimuli but did not affect accuracy on word stimuli, thus suggesting that Ss normally construct acoustic representations of words in the probe recognition task. Thompson & Massaro (1973) found that the degree of visual similarity of the probe alternatives had no effect on Ss' accuracy on word stimuli. This is consistent with the notion that the words are encoded into their acoustic forms. Moreover, Thompson & Massaro found that when the task was changed such that the S was encouraged to attend to only the middle letter of the word rather than the whole word, then an effect of probe similarity was obtained.

On the other hand, Baron & Thurston (1973) reasoned that if acoustic codes were being formed from the briefly presented words, then Ss would have more trouble choosing between two visually differing but acoustically identical alternative words than between two visually differing words which were not homophones. They found that Ss' accuracy when the alternatives were homophones did not differ from when the alternatives had different pronunciations. Spoehr & Smith (1973) found greater accuracy to one-syllable than to two-syllable 5-letter words in a probe recognition task, but found no syllable effect in the tachistoscopic report of two-digit numbers. They thus concluded that the effect of number of syllables on the perception of a briefly exposed word is due to factors other than the size of its acoustic representation. However, since it is possible that failure to find a syllable effect with digits was due to the absence of a matching process in the digit task or to a lower likelihood of acoustically encoding nonword stimuli, their conclusion remains less than fully convincing.

Krueger (1970c) tested for acoustic matching in the visual search task by comparing the RT to search for a target letter through an array of acoustically similar or dissimilar letters. Although previous researchers (e.g., Chase & Posner, 1965; Kaplan, Yonas, & Shurcliff, 1966) failed to find an effect of acoustic confusability on visual search, Krueger found that acoustic similarity caused a small (25 msec) decrement in the RT for searching the array. However, further analysis of Krueger's data indicated that the effect was mostly due to a relatively small subset of his Ss.[2]

To determine if acoustic representations are compared in the simultaneous matching task, Eichelman (1970) presented Ss with pairs of strings where one string was in upper-case letters and the other was in lower-case letters. Since the task was to respond SAME if both strings of a pair contained the same letters in the same order regardless of case, Ss were strongly encouraged to match acoustic representations of the different-case stimuli. The fact that the matching times for these different-case stimuli were longer than those for same-case stimuli (in a task where Ss were instructed to match on the basis of visual information) suggests that Ss do not usually match word names when both words are in the same case. However, as Krueger (1973) pointed out, if the WSE found by Eichelman was due to Ss matching word names on only some of the trials, then the RT difference between same-case and different-case matches would still occur.

Egeth & Blecker (1971) compared the matching RTs for 3-letter acronyms (such as FBI) with those for the same letters rearranged to form a word (e.g., FIB) and found almost no difference. Since the words could be pronounced as one syllable and the acronyms are normally pronounced as three syllables, the failure to find a difference in matching RTs is evidence that their acoustic representations were not what were being matched. However, in this study, Egeth & Blecker used only three word-acronym pairs and ran only 10 Ss for one session each. It is possible that their results would not generalize to other Ss and other word-acronym pairs.

In an attempt to directly test whether or not acoustic representations are what are being compared in a word matching task, Klapp (1971) compared the RTs for matching one- and two-syllable five-letter words. He found a 46 msec syllable effect for DIFFERENT responses, but none at all for SAME judgments. In a matching task where one- or two-syllable concrete nouns were paired with pictures, Klapp, Anderson, & Berrian (1973) again found no syllable effect for SAME matches, but this time found for DIFFERENT responses only a small (14 msec) syllable effect which was only marginally significant ($p < .10$, 18 Ss). Klapp et al. concluded that the matching of acoustic representations is a possible but unnecessary strategy for performing a word matching task.

To extend Baron & Thurston's (1973) finding on acoustic representations to the simultaneous matching task, Baron (1974) assembled two groups of word pairs which were exactly matched for degree of visual difference. However, the word pairs in one group were homophones while the pairs in the other group were not. Baron found no significant differences between the matching RTs of each group, thus providing evidence that Ss do not compare the acoustic representations of words in the matching task.

Compared to the amount of research done on whether acoustic representations are used in visual search, probe recognition, and matching tasks, few studies have been directed at the question of whether the word advantage shown in these tasks is due to some factor, other than the size of the acoustic representation, which acts exclusively on the comparison stage. By having Ss search for more than one target letter, Krueger (1970a) was able to increase the number of comparisons necessary for the visual search task without affecting the amount of encoding done. His finding that the size of the WSE was not affected by whether S searched for one, two, or three targets strongly suggests that the locus of the word advantage is in the encoding stage of the task. However, Krueger's results were based on data from only two Ss (one of whom was Krueger himself) who each were tested for at least eight sessions. Improvement in the task over sessions may have interacted with target set size and familiarity of the display in a way that masked the effect of multiple targets on the WSE.

E. Smith (1967) investigated the effect of word familiarity in a memory search task (cf., Sternberg, 1967). He found that the effect of probe word familiarity was independent of positive set size for the positive responses but interacted with positive set size for the negative responses. He concluded from this result that probe familiarity affects only the comparison process. To account for the effects of probe familiarity more precisely, Smith proposed that S checks his decision before responding; since there is only one comparison necessary for checking a positive response, but usually more than one comparison necessary for checking a negative response, probe familiarity would interact with positive set size only for negative responses. Comparing the matching time of words and nonwords, Schindler, Well, & Pollatsek (1973) found that the size of the WSE for DIFFERENT responses tended to increase as the position of the single differing letter pair varied from left to right. However, it was unclear from their data whether this effect was due to encoding or comparison processes.

Thus, although the visual search, probe recognition, and simultaneous matching tasks sharply limit the possible influence of memory and response factors, they introduce the possibility that the superior performance on words over nonword letter strings could be due to factors which operate on only the matching processes. A truly perceptual WSE would require that the encoding processes are also affected. Yet, as a review of some relevant studies has shown, the possibility has not been conclusively ruled out that the locus of the word advantage is solely in the matching stage. One purpose of the present study is to provide a new line of evidence that perceptual experience with letter strings causes those strings to be encoded more efficiently and not only be compared more rapidly.

An obvious test of the hypothesis that the WSE is due to the different sizes of the acoustic representations of words and nonwords would be to see if nonwords which are as pronounceable as words also have a large performance advantage over random letter strings. This has been done many times (e.g., Gibson, Pick, Osser, & Hammond, 1962; Baron & Thurston, 1973), and the results are that performance on pronounceable nonword stimuli approaches or equals that of word stimuli. However, these results do not bear on the issue of acoustic representations, since pronounceability is completely confounded with the rules and regularities of English orthography (see Gibson, Shurcliff, & Yonas, 1970, p. 71). A method for avoiding the problems of this confounding would be to equate the pronounceability of two sets of letter strings and then give Ss a great deal of visual experience with one of those sets (the repeated set). If, following this training, performance on the repeated strings in a perceptual task which controls for memory and response factors is superior to performance on the equally pronounceable set which was not repeated (the nonrepeated set), then the effect of experience on letter string perception is not due to differences in the size of acoustic representations.

In the present study the simultaneous matching task was used, but it is assumed that the results would not qualitatively differ if visual search or probe recognition tasks were used instead.[3] A letter set of twelve consonants was chosen, and all of the letter strings used in this study were random orderings of these twelve letters (no letter could be repeated in a single string). On a single trial, a letter string would be paired either with itself or with a letter string that differed from it in only one of its six positions. Further, when one of the letters in a string was not paired with itself, there was only one other letter it could be paired with. A letter and the only possible differing letter it could be paired with are called conjugates of each other, and the pair of letters is called a conjugate pair.

The purpose of grouping the twelve letters into six conjugate pairs were (1) to insure that repeated and nonrepeated strings could be paired with strings of comparable familiarity without adding redundancy to the differing repeated strings which would not also be present in the nonrepeated strings, and (2) to insure that during the entire period of perceptual training, each repeated string was paired with one of only six others. Thus, conjugate pairing allowed a test to be made of the possibility that learning to match a specific repeated letter string more rapidly is due to facilitation of the matching stage alone. If on the session following the last training session the conjugate pairings are changed, then, when a letter string differs, it will differ in a novel way. If the decreased matching time of the repeated strings is due to an adaptation of the matching process to the specific comparisons which it processed repeatedly over the training period, then this facilitation would occur to a lesser extent to a novel comparison, even if it is a repeated string which is being compared. Therefore, if the perceptual training causes changes in the matching stage only, the RT advantage of repeated over nonrepeated strings should be markedly reduced in the session where the conjugate pairings are changed.

WHAT IS LEARNED?

Perceptual training tasks, such as the one in the present study, are ideally suited for investigating the question of what is learned in the perceptual learning of letter strings. Presuming that letter strings which form words are perceptually encoded more rapidly or more efficiently than nonword letter strings, what information has the perceptual system taken from its experience with words which allows this encoding advantage to occur?

Several theorists (e.g., Gibson, 1969; Smith & Spoehr, 1974) have argued that the learning of the rules and regularities of English orthography is responsible for the WSE. However, it is unclear whether acquisition of a small number of very generally applicable spelling rules is sufficient to account for the perceptual advantage of words, or whether the storage of a very large number of "rules" which apply only to certain letter strings or letter groups must be postulated.

In a study where Ss' performance on words and pronounceable nonwords was compared using a probe recognition task, Baron & Thurston (1973) provided evidence that a limited number of very general rules is sufficient to account for the WSE. The pronounceable nonwords used in their study were constructed from the words they used by changing one of the nonprobed letters in the word to a letter which is allowable by general English spelling rules, but which causes the letter string to become a nonword. For instance, the pronounceable nonword corresponding to CARS was CORS; possible differences in discriminability between A and O were irrelevant since, for CARS and CORS, only the first and third letter positions were ever probed. In two separate experiments, Baron & Thurston found that although performance on word stimuli was superior to performance on nonword stimuli whose letters did not correspond to English orthographic rules, there was no difference between the accuracy to words and that to pronounceable nonwords. Thus, considering these results together with the results of their homophone study (which suggested that acoustic representations were not being used in their task), Baron & Thurston concluded that knowledge about general spelling rules (such as the tendency of vowels to occur in the middle of syllables) is responsible for the WSE.

On the other hand, it has often been reported (e.g., Howes & Solomon, 1951) that words which occur frequently in written English can be perceived more easily than infrequently occurring words. This word-frequency effect suggests that rule information which is specific and applicable to only a small number of stimuli can be learned from experience with letter strings, and that the learning of these specific rules can facilitate the perception of those strings. However, several authors (e.g., Newbigging, 1961; Broadbent, 1967) have presented evidence that the word-frequency effect is due to response factors rather than perceptual ones. For instance, Newbigging found that if frequent and rare words are tachistoscopically exposed for increasingly long durations, Ss are biased toward guessing more frequent words as responses on trials where only part of the stimulus was perceived. In addition, he found that Ss seem to require the perception of a larger stimulus fragment before they will venture an infrequently occurring word as a response.

However, even if it can be demonstrated that there is a perceptual component to the word-frequency effect, this perceptual difference may be attributable to differences between common and rare words on dimensions other than frequency of occurrence. For instance, Landauer & Streeter (1973) have shown that the overall letter frequency distribution differs for frequent and rarely occurring English words, and there may be other differences as well. Thus, comparing the perception of common and rare words is a relatively poor method for testing the hypothesis that specific information which can facilitate perception is acquired from experience with letter strings.

A more direct way of testing the hypothesis that specific rather than only general rules can facilitate perception is to vary the frequency of occurrence of a particular letter string and observe if such repetition causes the letter string to be perceived more rapidly. This has in fact been attempted many times, with mixed results. Solomon & Postman (1952) found that the shortest tachistoscopic exposure duration at which Ss could correctly report a 3-syllable nonsense word was closely related to the number of times S heard that nonsense word read aloud during the immediately preceding part of the experiment. However, when Goldiamond & Hawkins (1958) followed a similar procedure except that they tachistoscopically exposed a Rorschach figure rather than a nonsense word, they found the same relationship between frequency of prior exposure and verbal report. This indicates that the effect was due to response biases formed during the session. Goldstein & Ratleff (1961) varied the frequency of visual presentation of nonsense syllables, but tested recognition by using a forced choice procedure rather than by requiring full report. With response factors controlled in this way, they found no effect of prior exposure on perception, thus supporting the response bias explanation.

More recently, Earhard & Fullerton (1969) presented Ss with 96 consecutive brief exposures to 4-letter consonant strings. Ss' task on each exposure was either to indicate whether or not one of the letters in the string was thinner than the others or to indicate whether or not the exposed string was identical to a previously shown comparison string. Although Earhard & Fullerton found small improvements in accuracy, this result could have been due to general improvement in the task rather than specific improvement of perceptual processing. Krueger (1970b) studied the effects of specific frequency in a more controlled way by alternating repeated and nonrepeated display strings in a visual search task. He found that Ss searched more rapidly through repeated display sets whether the displays were words, nonwords, or even line figures. However, the fact that the effect appeared early in the session and did not increase as the session progressed indicated that this perceptual effect of stimulus repetition is too short-lived to be able to account for the rather permanent perceptual advantage of words over nonwords.

Thus the present study provides a unique opportunity for determining whether relatively specific information about letter strings can be stored to facilitate their perception. While the nonrepeated consonant strings were randomly chosen (with the constraints previously mentioned), the set of six letter strings which were repeated over the course of the training period was further constrained such that (1) no particular bigram, trigram, etc. appeared more than once in the repeated set, and that, (2) no letter appeared more than once in a single position. Therefore, the only kind of "rule" which could be learned about a repeated string would be specific to that string. S could not learn general rules such as "C is more likely to occur in the first position" or "D usually follows B". In fact, if information about letters is what is stored by the perceptual system, then there would have to be one "rule" for each letter in each of the six strings in the repeated set. Thus, if Ss can perceive such a repeated set of letter strings more rapidly than nonrepeated controls, then it must be possible to store very specific rule information in a form which can facilitate perception.

At least one group of early researchers (Erdmann and Dodge) proposed that it is the general shape of a word which allows it to be seen so rapidly. Mewhort (1966) found that changing the word shape by increasing the inter-letter spacing reduced the perceptual advantage of letter strings which were similar in letter structure to English words. This result suggests that stored information about visual features which span single letters is at least partially responsible for the rapid perception of words. Although recently Schindler, Well, & Pollatsek (1974) have found that changing the shape of six-letter words by segmenting the letters into pairs does not reduce the WSE, it is possible that that particular configurational change failed to destroy the between-letter features which happened to be crucial. A configurational change which may be more effective in destroying between-letter features is the presentation of the letters of a string in a vertical column rather than in a familiar row. If the perceptual facilitation of the repeated strings transfers to a task where vertically presented repeated and nonrepeated pairs must be matched, it argues for the relative unimportance of between-letter visual features in the perceptual learning of letter strings.

Gibson (1969, 1973) has proposed that information concerning the relative position of a letter or letter group is contained in the rules which facilitate the perception of words. In accounting for the finding that strings with word-like letter order were perceived more accurately than less constrained letter strings (e.g., Gibson, Pick, Osser, and Hammond, 1962), Gibson noted that the frequently occurring letter clusters in her stimuli "were not merely subunits created by high bigraph frequency; it was a cluster in its legal place in a word that facilitated recognition"(1973, p. 17). Evidence that such position information is stored has been provided by Zaslow (1972) who has shown that when commonly occurring consonant clusters are used as targets in a visual search task, _S_s can locate them faster when they searched through letter strings where the positions of the consonants followed the regularities of English orthography.

In order to investigate the importance of stored positional information in the perceptual learning of letter strings, an additional transfer task was given to the _S_s in the present study after they had completed the training period. In this task, _S_s matched 6-letter strings which were designed so that either the first or last 3 letters were the same as those of a repeated string while the rest of the string was a random sequence of the remaining letters of the set. Half of these "partially familiar" letter strings preserved the position of the familiar 3-letter sequence while in the other half, the position of the familiar sequence was shifted 3 positions to the right or left (thus yielding four types of partially familiar letter strings). If transfer of perceptual learning to those partially familiar strings which preserve the familiar group position is greater than the amount of transfer to the strings where the position of the familiar group is altered, then stored position information must play a role in the perceptual facilitation of repeated letter strings.

METHOD

SUBJECTS

Four University of Massachusetts psychology students served as paid Ss. Two Ss (LT and SB) were female undergraduates, one (LQ) was a female graduate student, and one (DK) was a male graduate student. Each S received payment of $36 after completing the first 21 sessions and an additional $4 after the completion of the last two sessions. All Ss were right-handed.

APPARATUS AND MANNER OF STIMULUS PRESENTATION

A Hewlett-Packard 2114B computer controlled the presentation of capital letters on an HP 1300A X-Y display oscilloscope. It also recorded S's responses and measured the response time in milliseconds. Ss were run individually and sat approximately 1.5m. from the oscilloscope screen, in a dimly lit room.

The display for a single trial consisted to two six-letter strings with one string directly above the other (see Figure 1a). Each of the letters in a string was constructed by illuminating the appropriate pattern of points in a matrix 13 points high and 9 points wide. A single letter was 1.00 cm. high and .87 cm. wide, and there was .21 cm. between letters. The letter strings were 6.28 cm. long and subtended $2^{\circ}22'$ of visual angle. The vertical distance between the two strings was 1.74 cm. and hence the total vertical visual angle subtended was $1^{\circ}30'$.

PROCEDURE

The experiment consisted of twenty-three 45-minute sessions. The first 16 were termed "training" sessions, and the last 7 were considered "transfer" or "retention" sessions. The procedure was essentially the same for all sessions except Session 21.

At the beginning of Session 1, Ss were given a copy of the instructions (see Appendix I) which they read immediately. They were told to keep their copy and bring it to future sessions for possible reference. Before each session, Ss were reminded to "take as much time as you need to make the correct response, but no more". At the beginning of each of the transfer sessions, Ss were told that the stimuli would differ from what they had been seeing and were told in general terms what the difference would be.

(a)	DNJKHB	LFPBJM
	DNJKHB	LFPGJM

(b)	D D	B B
	M M	C C
	N N	H H
	G G	M M
	F F	D P
	J J	N N

Figure 1. Examples of (a) normal horizontal display, and (b) vertical letter string presentation used on Session 18.

Each session began with at least one practice block consisting of 24 pairs of random 6-digit strings. For Session 1 Ss were given one extra practice block since the task was new to them. For Sessions 22 and 23 they were given an extra practice block since they had been away from the task for a comparatively long period of time. Following the practice block(s), each S was given four blocks, each consisting of 48 pairs of 6-letter strings. S initiated each block when he was ready; the interval between trial blocks varied from 1-2 minutes.

A single trial began with the presentation of a fixation point (a "+") in the center of the screen for 1 second and was followed by blank screen for 500 msec. Then the pair of strings was displayed. The strings remained on until S responded by pressing the appropriate key on the response panel in front of him. Of the ten keys on the response panel, the leftmost key always indicated a SAME response and the rightmost key always indicated a DIFFERENT response. Following S's response, feedback, which consisted of the RT in msec for a correct response and the word "error" for an incorrect response, was displayed in the lower left-hand corner of the screen. When Ss responded incorrectly, the sequence of the trial block paused until S indicated by pressing a middle key that he was ready to continue. The interval between the feedback for a correct response and the beginning of the next trial was 1 second.

For Session 21, S was given instructions appropriate for the probe recognition task (cf., Reicher, 1969). As in the RT sessions, the trials were grouped into four blocks of 48. S initiated each trial by pressing a middle key. One second later, a single 6-letter string was briefly presented and was followed by a mask of 6 asterisks. The probe alternatives appeared above the asterisks at the position of the probed letter and remained visible for five seconds. S responded by pressing the leftmost key to choose the upper alternative and the rightmost key to choose the lower one. The stimulus duration at which S performed at 75% accuracy was roughly estimated from his performance on 3 or 4 practice blocks. The mean stimulus duration for the four Ss was 412 msec.

STIMULI AND DESIGN

Every letter string used in the study was a sequence of six consonants from the following set:

B	C	D	F	K	N
G	J	P	H	M	L

Each column represents a conjugate pair. Pairings were arbitrary except that the letters containing curved lines were paired with each other; this was done to lessen the chances that the members of a conjugate pair could be discriminated after the extraction of only one gross visual feature. In the presentation of a pair of letter strings during a trial, every letter was paired with either itself or with its conjugate. This was true for both repeated and nonrepeated strings.

Each trial block was generated by the computer from one or two sets of six "prototype" letter strings. If a set of repeated prototypes was used, the resulting trial block was termed "repeated"; if a nonrepeated set of prototypes was used, a "nonrepeated" block resulted; and if both a repeated prototype set and a nonrepeated set were used in the formation of a trial block, the resulting block was termed "mixed".

A trial block consisted of 48 repetitions of the following sequence. First a prototype letter string was chosen randomly from one or two prototype sets. Then it was randomly decided whether the strings on that trial would be the same or different.[4] If the strings were to be the same, then the chosen string was duplicated and the identical pair of strings was displayed. If the strings were to differ, a single position of difference was randomly chosen (from the 6 possibilities) and the comparison string was constructed by duplicating the prototype string on all positions except the differing one; in that position, the conjugate of the letter in the differing position was used. Finally, it was randomly decided whether the prototype or its companion string would occupy the upper position in the display, and then the stimulus pair was presented.

Each string of the 4 sets of repeated prototypes was written into the program and consisted of a randomly chosen member of each of the six conjugate pairs. In order to make it impossible (1) for any letter in a repeated prototype set to appear more than once in a single position, and (2) for any single sequence of letters to appear more than once in a set of repeated prototypes, the orderings of the conjugate pairs of the six repeated prototypes were as follows:

1	2	3	4	5	6
2	4	6	1	3	5
3	6	2	5	1	4
4	1	5	2	6	3
6	5	4	3	2	1

Each row designates one of the six prototype strings in a repeated set, and each number designates one of the six conjugate pairs.

For each *S*, a given conjugate pair had a different (randomly chosen) conjugate pair number. Thus, the repeated prototypes for each *S* were totally different, although under precisely the same constraints. This was designed to reduce the confounding of the effects of string repetition on perception with the visual properties of any particular set of repeated strings. The set of prototypes used for each *S* are presented in Table 1.

A nonrepeated prototype set was generated anew before each nonrepeated or mixed trial block. The procedure was to sample from the six conjugate pairs without replacement, and to randomly choose a member of each pair chosen. Strings so generated which happened to be identical to a repeated prototype (or which had a conjugate which was identical to a repeated prototype) were discarded. Although the strings of

Table 1

Repeated prototypes used for each S

LT	DK	SB	LQ
NJPFMG	GPCFLK	MNFBDC	JHLMDB
CFGLDK	DFKBJN	LBCKHP	FMBCNP
PBJMNF	CMPLGF	FJNDMB	LGHDJM
HNKJGD	HGNPKJ	GMPNCH	KJPNBN
KDNBFJ	NJGMFP	PHMJBN	PNJGMH
BMFPJL	MLFCPB	JDBFNK	GDMLHC

Table 2

Examples of nonrepeated prototype sets

MDBFNC	BDMCNF
GFLKDC	JFGNKD
CNFGPK	FMCBPL
BKDFJN	NPGJMF
CPKLFB	HLJKPG
LCFPMB	DMNGFJ

a set generated in this way could occasionally have had letter sequences in common (while repeated strings could not), this would, if anything, tend to enhance the perception of the nonrepeated strings relative to the repeated strings, and thus was not considered a problem. Two examples of a nonrepeated prototype set are displayed in Table 2.

Table 3 summarizes the order of trial blocks each S received during the 23 sessions of the study. The first 21 sessions were on consecutive weekdays beginning with a Monday. Session 22 was on the Friday following Session 21, and Session 23 was on the sixth Friday after Session 22. Thus, the duration of the experiment for each S was almost three months. An attempt was made to run a S at the same time each day.

Sessions 1 through 16 were training sessions. Six repeated letter strings were used on half the trials of a session, and newly generated nonrepeated strings were used on the other half. Two mixed blocks were given during Session 1 to determine if the larger stimulus set of a mixed block affected RT. At the end of Session 16, each S was given 10 minutes of interpolated activity (i.e., conversation) and then was given a list of 24 6-letter strings typed in captial letters. S was told that he had seen six of the strings on the list many times during the experiment, while the other 18 were probably completely novel. He was asked

Table 3

Order of trial blocks for each S for each session
(R=repeated trial block, N=nonrepeated block, M=mixed block)

Session#	Session Type	Subject LT	DK	SB	LQ
1	training	RMNM	NMRM	MRMN	MNMR
2	training	NRNR	RNRN	NRNR	RNRN
3	training	RNRN	NRNR	RNRN	NRNR
4	training	NRNR	RNRN	NRNR	RNRN
5	training	RNRN	NRNR	RNRN	NRNR
6	training	NRNR	RNRN	NRNR	RNRN
7	training	RNRN	NRNR	RNRN	NRNR
8	training	NRNR	RNRN	NRNR	RNRN
9	training	RNRN	NRNR	RNRN	NRNR
10	training	NRNR	RNRN	NRNR	RNRN
11	training	RNRN	NRNR	RNRN	NRNR
12	training	NRNR	RNRN	NRNR	RNRN
13	training	RNRN	NRNR	RNRN	NRNR
14	training	NRNR	RNRN	NRNR	RNRN
15	training	RNRN	NRNR	RNRN	NRNR
16	training (also forced choice recognition test)	NRNR	RNRN	NRNR	RNRN
17	new conjugate pairings	RNRN	NRNR	RNRN	NRNR
18	vertically presented strings	NRNR	RNRN	NRNR	RNRN
19	partially familiar strings	MM[a]MM[a]	MM[a]MM[a]	MM[a]MM[a]	MM[a]MM[a]
20	retention - baseline	NRNR	RNRN	NRNR	RNRN
21	probe recognition task	RNRN	NRNR	MMMM	MMMM
22	retention	RMNM	NMRM	MRMN	MNMR
23	retention	RMNM	NMRM	MRMN	MNMR

[a]Trial block data lost due to E's error

to circle the six strings he had seen before.

Sessions 17 through 19 were the transfer sessions. Session 17 was identical to Sessions 2-16, except that new conjugate pairings were assigned to each S. On Session 18, the letter strings were presented in vertical columns (see Figure 1b). Session 19 consisted of four mixed blocks of the four types of partially familiar strings (see Figure 2).

Session 20 was run to serve as a baseline for the retention sessions. After Session 20, Ss were asked to give written answers to some open-ended questions concerning their matching strategies and their general reactions to the experimental situation. Session 21 was included as an attempt to provide a converging operation to show that the effect of stimulus repetition found in this study was a truly perceptual phenomenon rather than an artifact in the task. Finally, Sessions 22 and 23 were run to investigate the permanence of the perceptual changes resulting from long-term letter string repetition.

RESULTS

TRAINING SESSIONS

The RT data[5] for the training sessions (15,288 observations) were reduced to 512 numbers by calculating the mean for each response type, for the repeated and nonrepeated strings, for each S, for each pair of trial blocks in a day, for each of the 16 days of training. A four-way analysis of variance and linear trend analysis were performed on these

(a) If ABCDEF is a repeated letter string, then the partially familiar strings derived from it are as follows:

ABCXXX	XXXABC	(X = random letter)
XXXDEF	DEFXXX	

(b) NDKMNP DNLFMG

LDKMNP DNLFMG

Figure 2. (a) construction of the partially familiar strings used in Session 19, and (b) examples of partially familiar strings used for Subject LT (familiar portions of the strings are circled).

means. The results of these analyses can be seen in Appendix II. Since the only significant effect of the Blocks (i.e., half-sessions) variable was a third-order interaction which was not easily interpretable, and since an unequal number of observations were used to compute each mean, this set of means was not further used. Instead, in an attempt to reduce the random variability due to the unequal weightings of individual RTs, the weighted mean of each pair of half-session means was calculated, thus reducing the data to 256 numbers.

A three-way ANOVA and a linear trend analysis were performed on these means, and the results are summarized in Appendix IV (the means of the 4 Ss for each day and condition are in Appendix III). There was a significant decrease in RT ($F_{(15,45)} = 16.67$, $p < .001$) over the course of the training period. As can be seen in Figure 3, RT decreased steadily with practice until Session 11 or 12 where it appeared to level off. Further it is also clear from Figure 3 that the RT decrease over sessions was not due to a speed-accuracy trade-off since the error rate was higher on the first session than on succeeding training sessions and did not appear to vary systematically with RT.

The significant main effect of letter string familiarity ($F_{(1,3)} = 66.08$, $p < .005$) is illustrated in Figure 4. On every session except Session 2, the repeated strings were matched faster, on the average, than the nonrepeated strings. However, the size of the repeated string advantage (familiarity

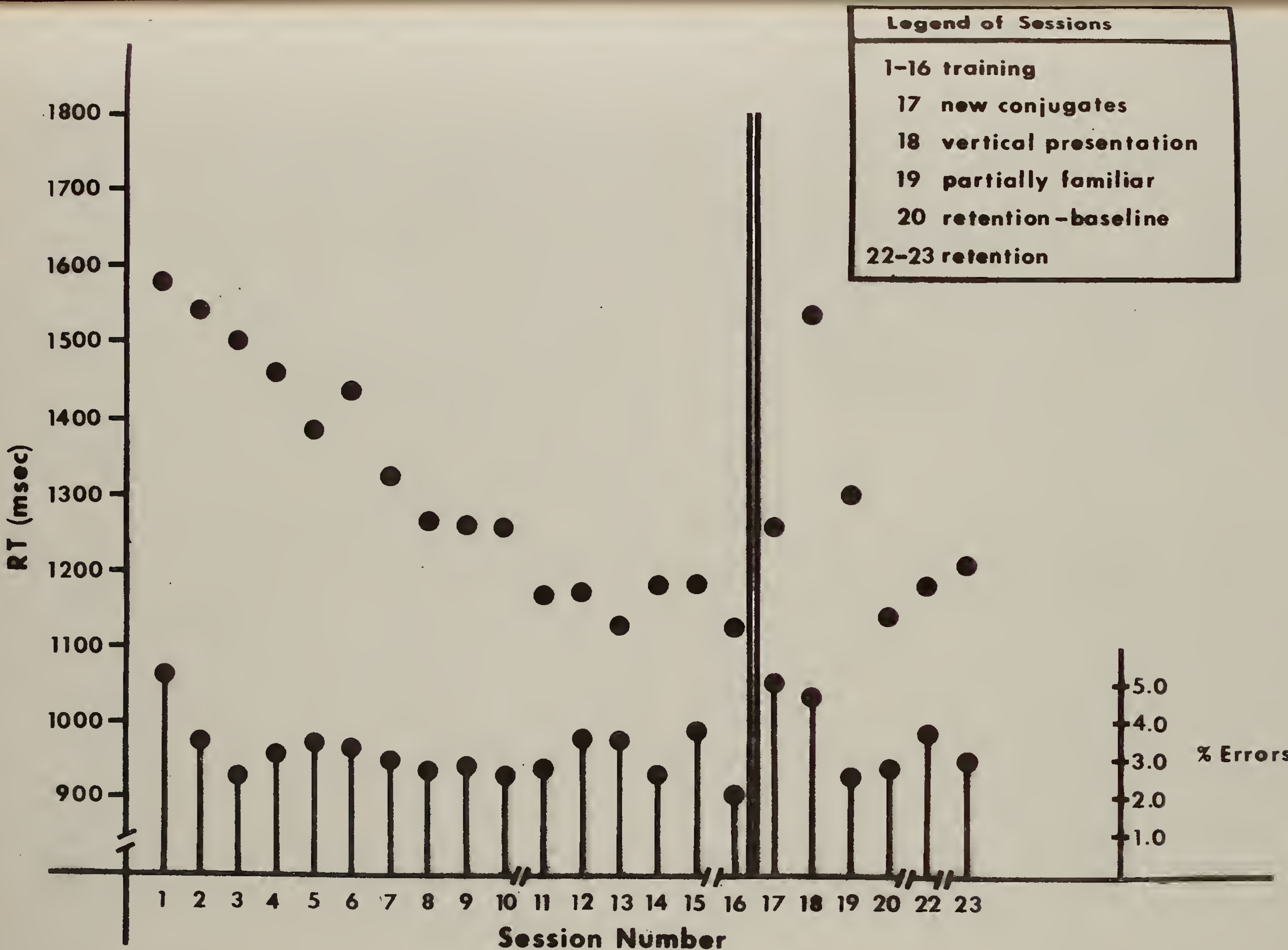

Figure 3. Mean RT and error rate for each experimental session

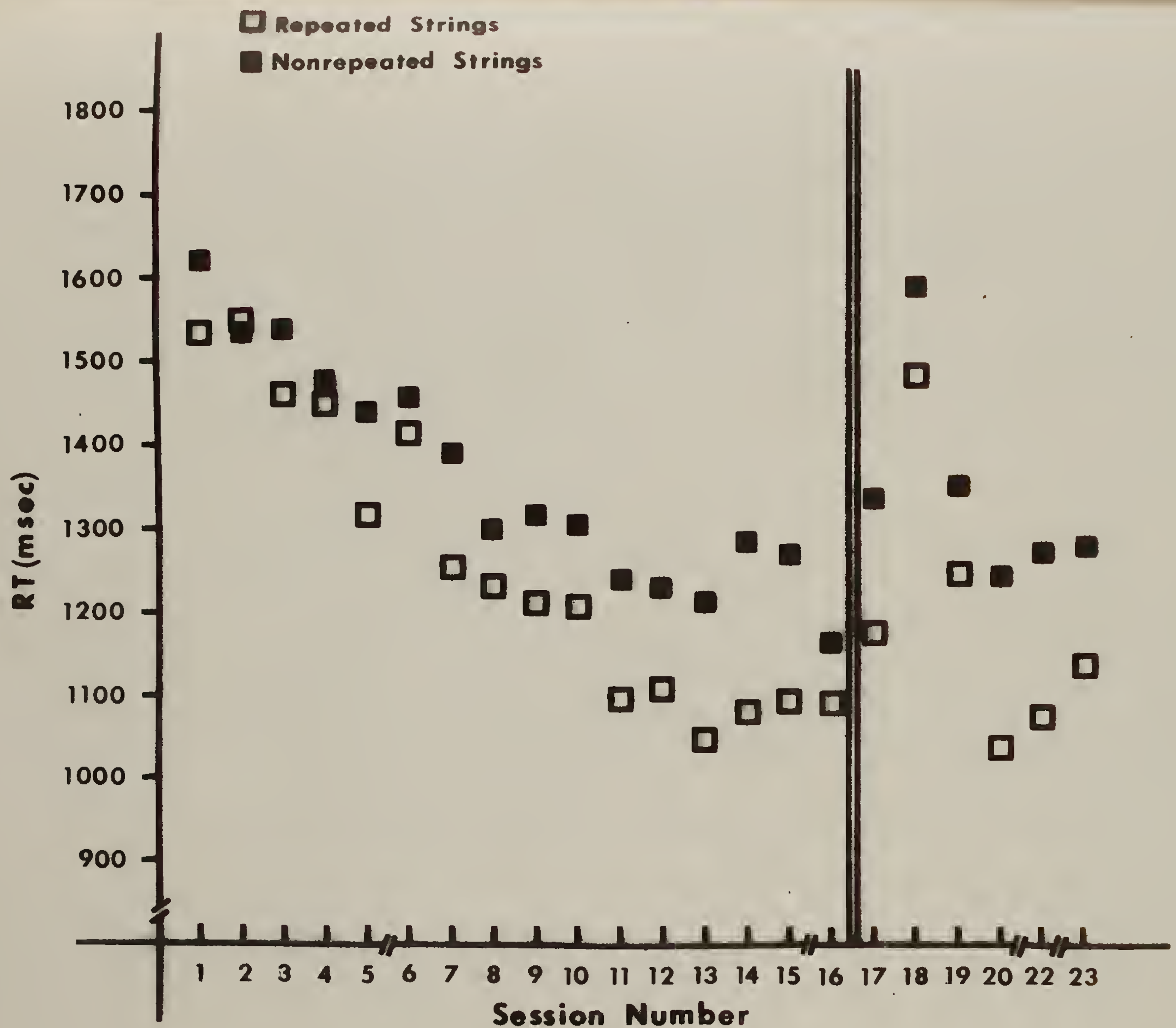

Figure 4. Mean RT for repeated and nonrepeated stimuli for each session

effect, FE) increased significantly over training sessions (see Figure 5) yielding a significant FxD_{lin} interaction ($F_{(1,3)} = 17.06$, $p < .05$). The remainder of the FxD interaction was not significant ($F_{(14,42)} = 1.27$, $p > .20$), implying that the advantage of repeated over nonrepeated strings rose in a roughly linear fashion. The slope of the best-fitting straight line was 6.77 msec/session and its intercept was 46.20 msec. This suggests that, although the familiarity effect increased over sessions, there was a small initial advantage of the repeated stimuli. It may very well have been that one or more of the letter strings randomly chosen to be repeated happened by chance to be able to be matched more rapidly than the average nonrepeated string.

There are several probable causes for the large amount of random variation in the size of the familiarity effect over days. First, on all training days except the first, the familiarity manipulation (repeated vs. nonrepeated) was a totally between-blocks variable. Since any changes in S's mood and/or motivation are more likely to occur between blocks than within them, the variability associated with such changes increased the variability of the familiarity effect for a session. Also, the difference between the repeated and nonrepeated strings is probably more susceptible to the inevitable variations in S's motivation between days; if S wants to "slack off" during the task, it is more likely that he will take extra time on the easier matches since the

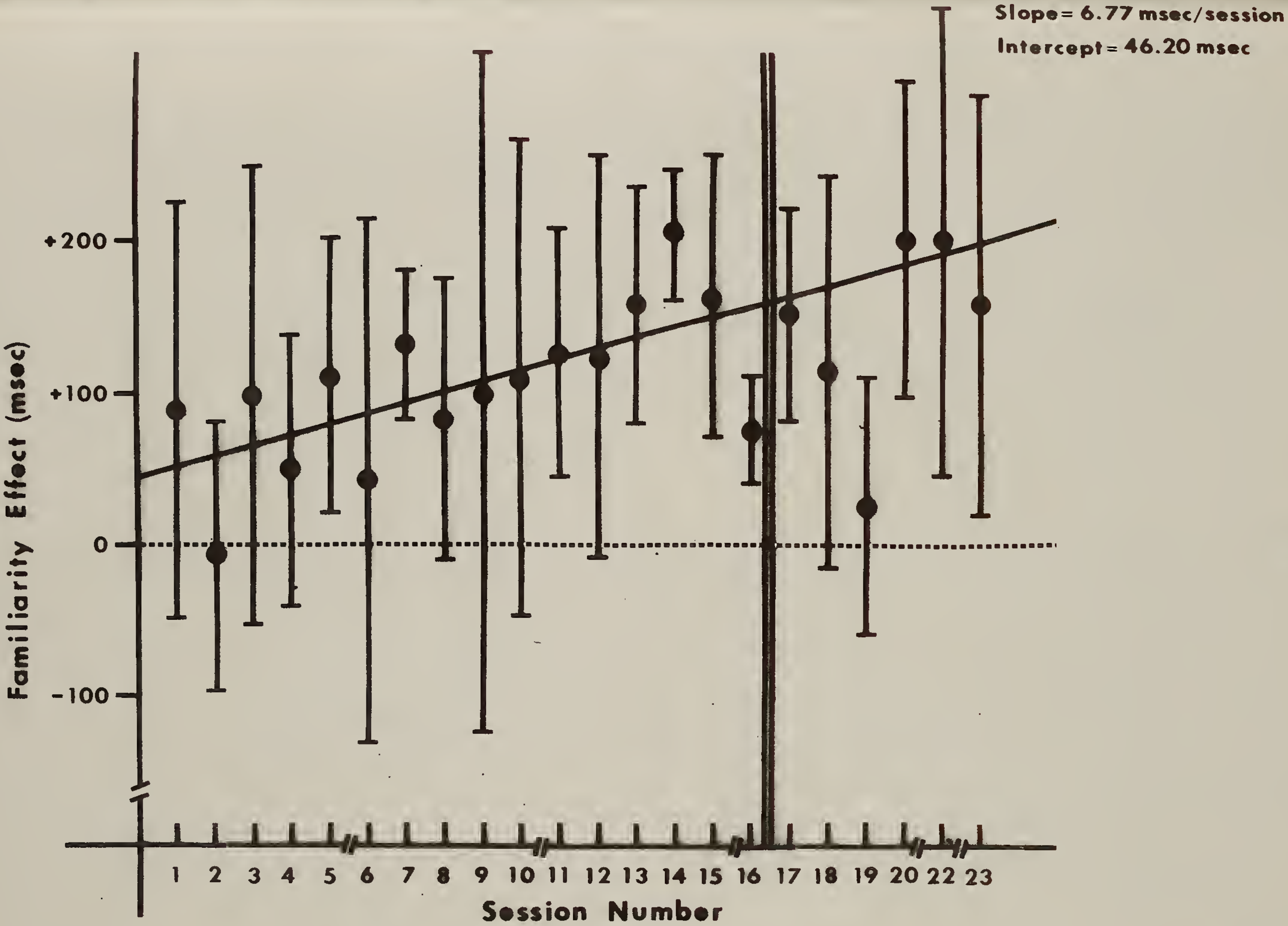

Figure 5. Mean familiarity effect & confidence interval for each session, and best-fitting straight line for Sessions 1-16 (best linear fit accounts for 40.3% of Session 1-16 variance)

resulting absence of very long RTs would tend to conceal his temporary failure to respond as quickly as possible. Finally, the variability due to the continual change of stimuli in the nonrepeated condition also adds to the variability of the FE. An analysis of variance on the standard errors of each of the 352 means calculated from the 22 sessions showed that the nonrepeated RTs were indeed more variable ($F_{(1,3)} = 24.24$, $p < .025$).

In order to further illustrate the increase in the advantage of repeated over nonrepeated strings which occurred during the training sessions, the curve in Figure 5 was "smoothed" by plotting the means of overlapping groups of three sessions (see Figure 6). This smoothed function is quite linear (the best fitting line accounts for 89% of the variance), and it indicates that the advantage due to letter string repetition increased steadily over the course of the training period.

The significant response by familiarity interaction ($F_{(1,3)} = 40.45$, $p < .01$) is illustrated in Figure 7. Clearly, the effects of string familiarity are smaller for DIFFERENT responses than for SAME responses. However, it is probably not the case that only SAME matches were facilitated by stimulus repetition. It is more likely that DIFFERENT responses were affected by stimulus familiarity to a lesser extent than were SAME responses, and that given the large amount of random variability in the study, this smaller

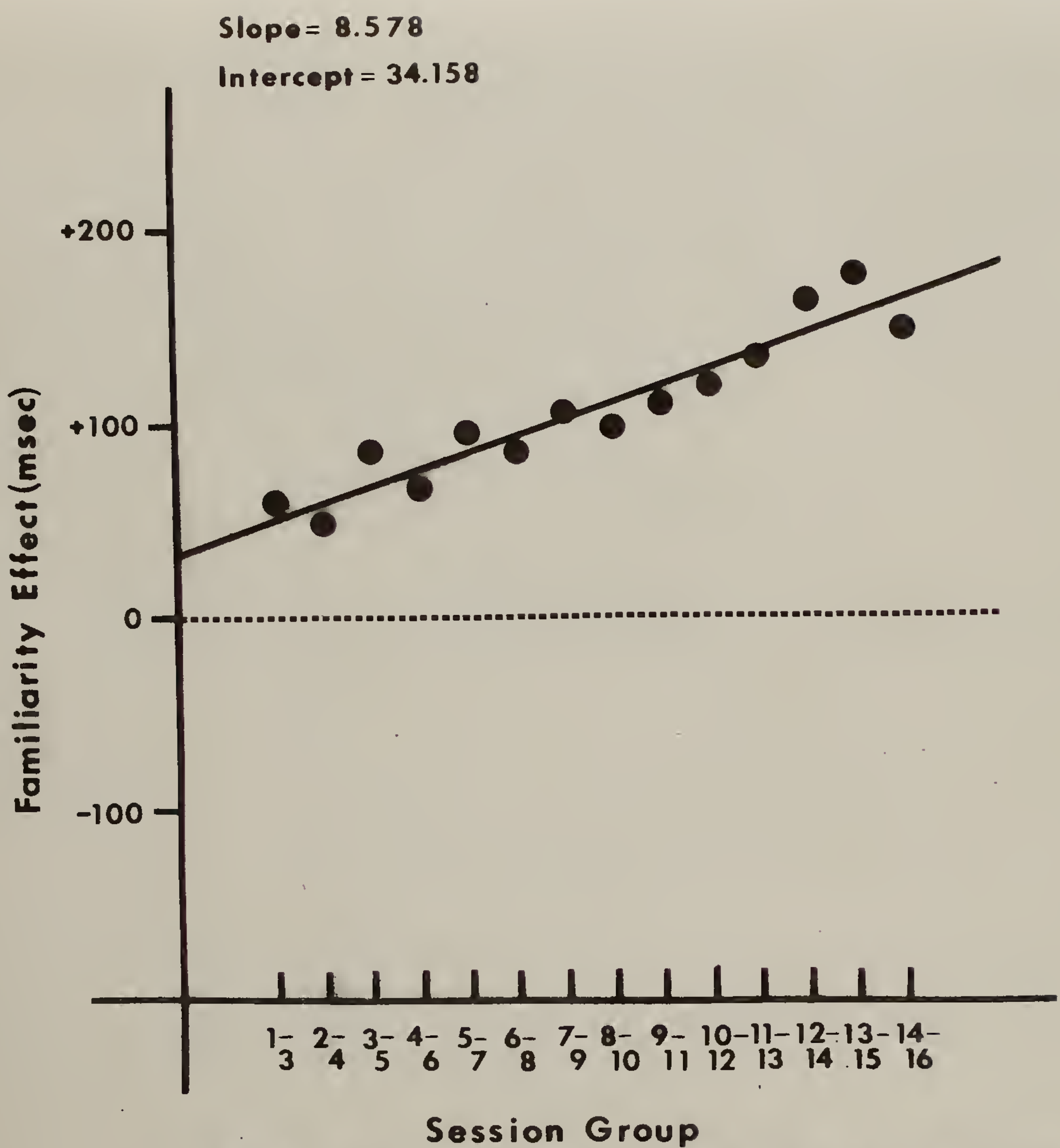

Figure 6. Mean familiarity effect for each group of three training sessions. The best-fitting straight line accounts for 89.1% of the variance.

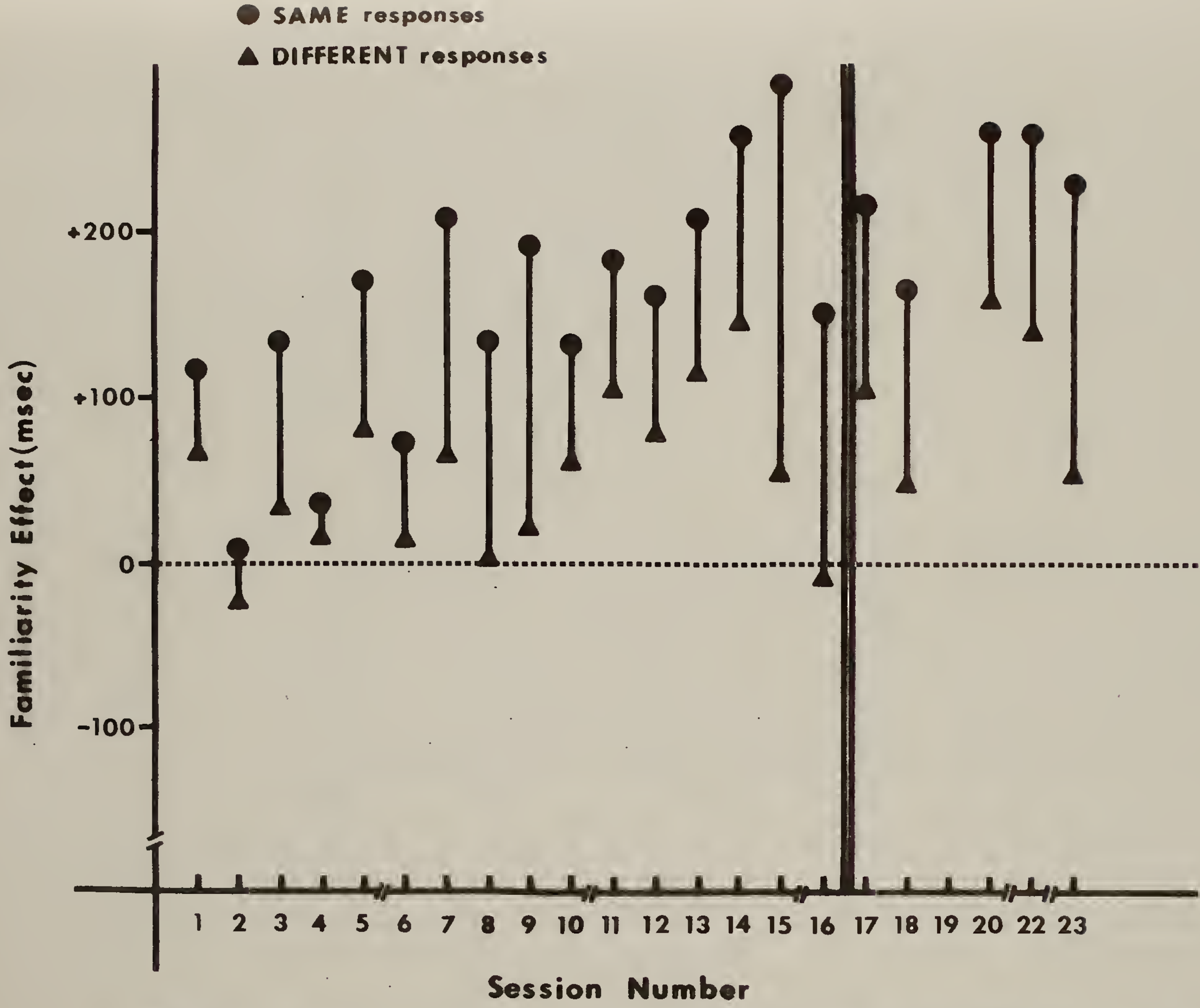

Figure 7. Mean familiarity effect for SAME and DIFFERENT responses for each session

effect could not be shown (the effect of familiarity on DIFFERENT responses did not increase significantly over sessions, $F < 1$). Evidence supporting this explanation is that the correlation of the daily mean familiarity effect for SAME responses with that for DIFFERENT responses was quite large ($r = .723$, $p < .001$).

To investigate the speed of DIFFERENT responses as a function of the position of the difference in the string, the DIFFERENT RTs for each subject-session were used to calculate 24 means (6 positions of difference x 2 levels of familiarity x 2 half-sessions). However, because of the small number of observations which contributed to each mean, the error due to unequal weighting of individual RTs was very large. In fact, some means were equal to zero because there had been no trials in those particular conditions. So, to reduce this weighting error, the RT data from training sessions 1-8 were used to compute only 24 means for each S. A similar form of collapsing was also done for training sessions 9-16. A four-way ANOVA was performed on those means and the results are summarized in Appendix VI (the means themselves are in Appendix V).

The position of the difference in the letter string significantly affected the mean RT to respond DIFFERENT ($F_{(5,15)} = 46.68$, $p < .001$). The form of this relationship can be seen in Figure 8. There are at least two plausible matching strategies which are consistent with these data.

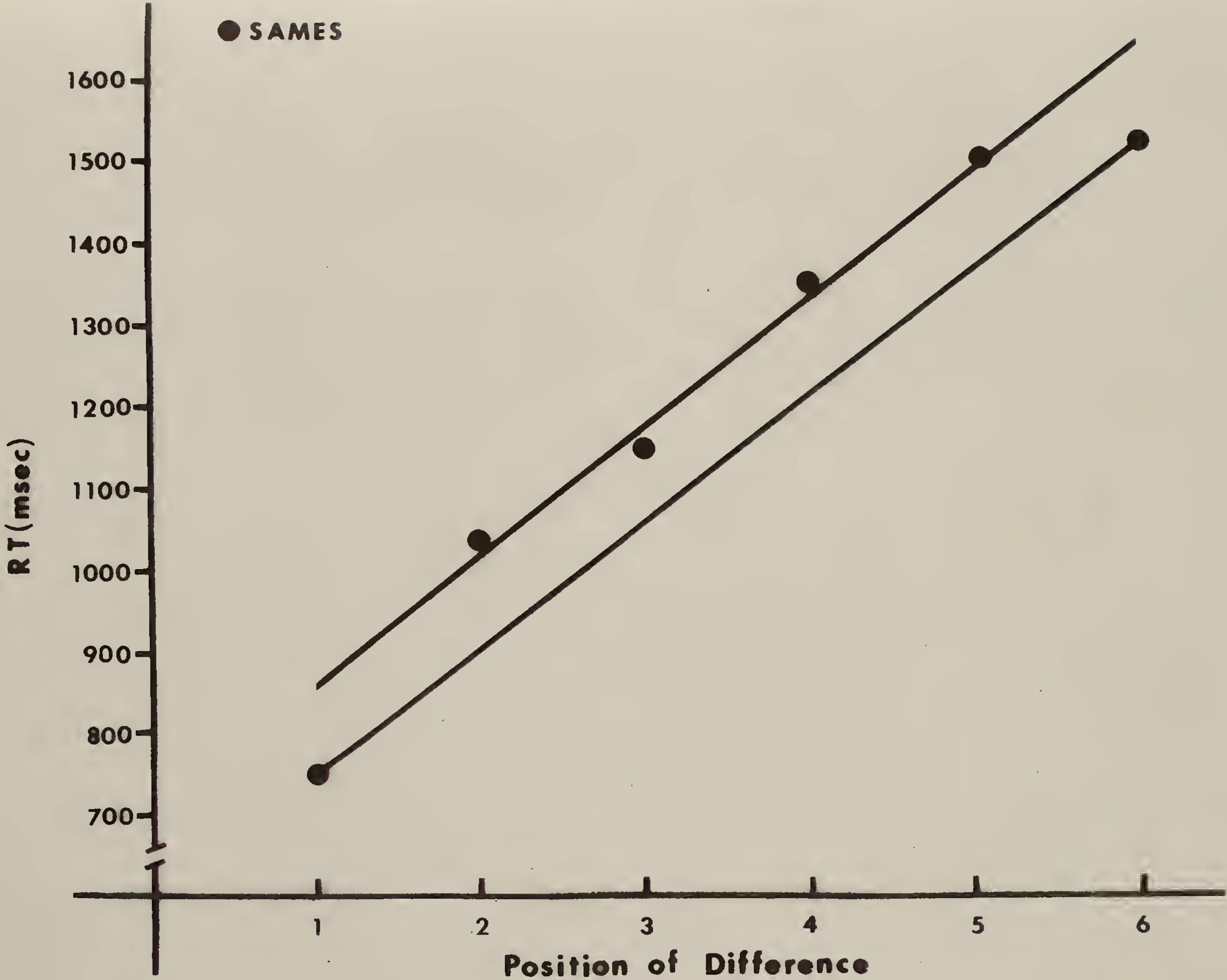

Figure 8. Mean RT for DIFFERENT responses as a function of the position of difference. Best-fitting straight line connecting positions 2–5 accounts for 99.5% of the variance.

The monotonic increase in RT from position 1 to position 6 suggests that Ss used a left-to-right serial self-terminating scan in this task. Further, the function appears to be negatively accelerated, thus suggesting that Ss scan more rapidly as they get further into the letter string, at least some of the time. On the other hand, the RTs for positions 2-5 seem to be on the same line, and the matching times for differences in positions 1 and 6 appear to be faster (by equal amounts) than would be predicted from the best fitting line joining the times for positions 2-5 (see Figure 8). This could be interpreted as indicating that often a left-to-right serial self-terminating matching process is used, but that sometimes matches are made without scanning. These "wholistic" matches would be faster than those made by scanning, and would occur more often for differences at positions 1 and 6, since those positions are less affected by lateral masking by neighboring letters.

The effect of letter string familiarity on DIFFERENT RT varied with the position of the difference in the string ($F_{(5,15)} = 5.63$, $p < .005$). Generally, the perceptual advantage of repeated over nonrepeated strings increased with increasing left-to-right position of difference (see Figure 9). A separate ANOVA was run on the data for each serial position, and the results are summarized in Table 4. There appears to be no effect of familiarity for positions 1 and 2, a small one at position 3, and a larger one at position 4.

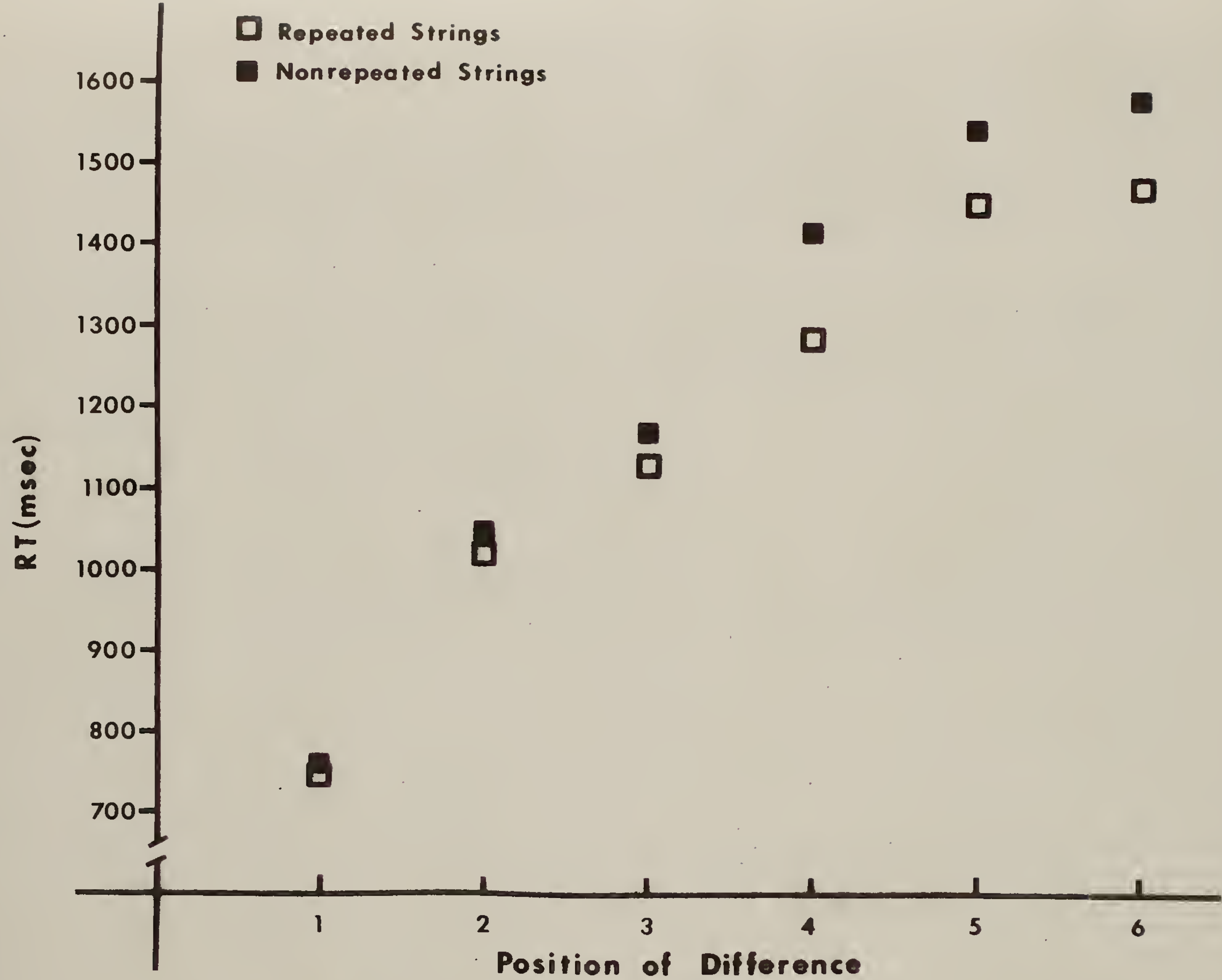

Figure 9. RT for a DIFFERENT response as a function of the position of difference for repeated and nonrepeated stimuli

However, the size of the familiarity effects at positions 5 and 6 are, if anything, smaller than the effect at position 4.

During the training sessions, there were only six letter discriminations possible, one corresponding to each of the conjugate pairs. Since, over the 16 sessions, every conjugate pair occurred approximately equally often in each position for both repeated and nonrepeated pairs, the relative discriminability of the members of a conjugate pair should be the same for repeated and nonrepeated strings. However, if the continual presence of a specific letter context changes the discriminability of a pair (e.g., by allowing the formation of featural units which span single letters) then the relative discriminability of the six pairs should be different for the repeated and nonrepeated stimuli. The mean RTs to each conjugate pair for repeated and nonrepeated strings can be seen in Table 5. Repeated string matches were in general faster than nonrepeated ones, but there was no significant interaction of familiarity with discriminability of conjugate pairs ($F < 1$). Moreover, the repeated and nonrepeated means for each conjugate pair covaried ($r = .84$, $p < .05$), thus suggesting that the existence of an unchanging letter context does not affect the relative discriminability of a letter pair.

TRANSFER AND RETENTION SESSIONS

The overall RTs and error rates for the transfer and

Table 4

Familiarity effect for string pairs differing at each position

Position of difference	FE (in msec)	F(df = 1,3)	P
1	11	< 1	-
2	20	< 1	-
3	40	21.36	< .025
4	124	152.76	< .005
5	90	28.06	< .025
6	105	22.68	< .025

Table 5

RT to each conjugate pair for repeated and nonrepeated strings

Conjugate pair	RT for repeated strings	RT for nonrepeated strings
C-J	1131	1158
B-G	1147	1235
N-L	1166	1231
D-P	1192	1237
M-K	1225	1322
F-H	1233	1265

retention sessions are displayed in Figure 3. For each S, the mean RT for Sessions 13-16 was computed and these means were compared with the mean RT for each S on the transfer and retention sessions. The results of these comparisons are displayed in Table 6.

The mean familiarity effect for each S on each of the 16 sessions was computed directly from the observed RTs. For each S, the best-fitting straight line through those points was used to derive a projected estimate of the Session 17 familiarity effect. These projections were compared with the directly calculated familiarity effects for each S for the transfer and retention sessions. The results of these comparisons can be seen in Table 7.

Although the use of new conjugate pairings appeared to have little effect on RT or on the FE, the vertical presentation of the stimuli increased RT significantly ($t_{(3)} = 5.99$, $p < .01$) while causing no reliable change in the size of the FE. For Session 19, no significant difference in overall RT was found. However, the advantage of trigrams in familiar positions over trigrams in unfamiliar positions was 58 msec smaller than the projected Session 17 familiarity effect, and this difference was marginally significant by a two-tailed t-test ($t_{(3)} = 3.10$, $p < .10$). The obtained decrease in the familiarity effect was expected for this session since only half of each string was familiar. The important result of session 19 is that letter strings with familiar trigrams in

Table 6

Comparison of transfer and retention session RT

with mean RT for Sessions 13-16

Mean RT for Sessions 13-16 = 1156 msec

Session#	mean RT	mean RT for Sessions 13-16	$t_{(3)}$	P (two-tailed)
17	1257	101	1.20	-
18	1536	379	5.99	< .01
19	1300	144	1.47	-
20	1141	-15	0.29	-
22	1177	21	0.32	-
23	1207	51	0.73	-

Table 7

Comparison of transfer and retention session FE

with projected FE for Session 17

Projected FE for Session 17 = 161 msec

Session #	mean FE	projected FE-mean FE	$t_{(3)}$	P (two-tailed)
17	150	111	0.43	-
18	114	47	1.35	-
19	103	58	3.10	$p < .10$
20	201	-40	2.84	$p < .10$
22	201	-40	0.76	-
23	158	3	0.06	-

familiar positions were matched faster than those with familiar trigrams in unfamiliar positions ($F_{(1,3)} = 22.10$, $p < .025$). The serial position curves for DIFFERENT responses for Sessions 17-19 can be seen in Figure 10. Since each point of a serial position curve for one day represents relatively few RTs (< 60), the functions displayed in Figure 10 are probably not very reliable.

The increased FE (marginally significant, $t_{(3)} = 2.84$, $p < .10$) on Session 20 could indicate that visual experience with the repeated stimuli during the transfer tasks served to decrease their matching time even further. The fact that the advantage of repeated strings did not decrease significantly on sessions 22 and 23 suggests that the effects of stimulus repetition during the training period were relatively long-lasting. Also, since Sessions 22 and 23 consisted of both mixed and separated blocks of repeated and nonrepeated strings, the effect of type of trial block on the FE was able to be assessed. The mean FE for the mixed blocks was 9 msec larger than that in the separated blocks. This difference was not significant ($t_{(3)} = .38$, $p > .40$).[7]

The results of the probe recognition task (session 21) were clouded because (1) the stimulus durations used were probably excessive, and because (2) two Ss were shown repeated and nonrepeated letter strings in separate blocks, while the other two Ss were shown blocks of mixed repeated and nonrepeated stimuli. The blocking procedures was changed after the

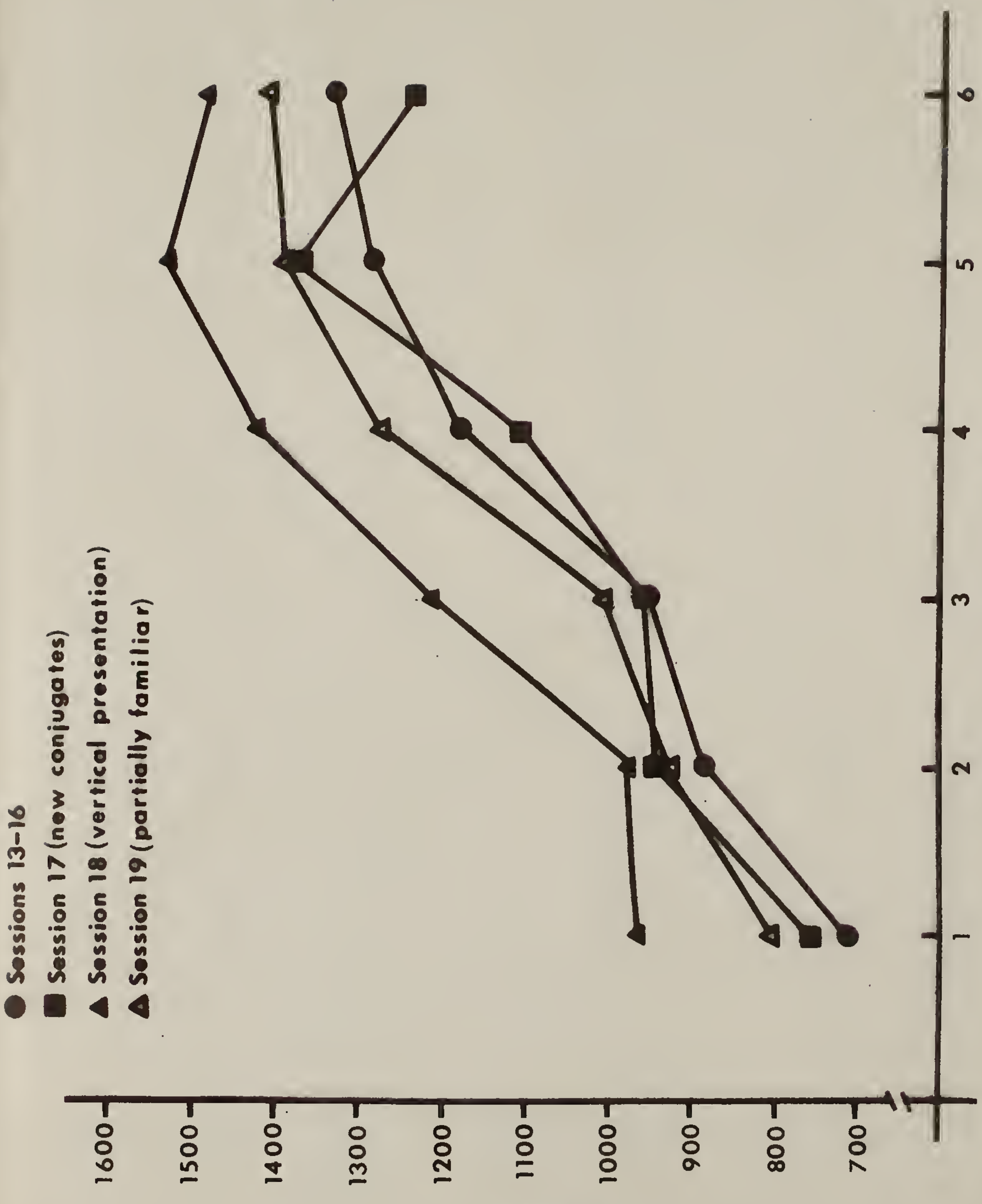

Figure 10. Letter position curves for transfer sessions

first two _S_s were run because it was clear that a within-session increase in accuracy due to practice was the overriding factor in the results. The percentage correct for repeated and nonrepeated strings for each letter position probed can be seen in Table 8. Also in Table 8 are the results of an ANOVA performed on the arcsine transformation of the data. Although the effect of letter string familiarity was not significant, it is interesting that the letter position curves have a shape similar to those obtained from the matching task. Also, whatever familiarity effects there are, occur mainly in positions 4 through 6.

The results of the forced choice recognition task and the specific confusion errors made can be seen in Table 9. It is interesting that after 16 sessions of many repetitions per session, not one _S_ could recognize all six of the repeated letter strings. Although, on the average, detractors had three letters in common with a repeated string, five out of the seven incorrect responses had four or five letters in common with the correct letter string. This result suggests that at least some perceptual information had been stored even on the strings which were not correctly recognized.

SHORT-TERM REPETITION EFFECTS

Since every trial block in the study (except for the mixed blocks) was generated from a set of only six prototypes, there were many stimulus repetitions during a trial block. To assess the effect of within-block repetition, the RTs of non-

Table 8

Results of probe recognition task (Session 21)

(a) Percentage correct for repeated and nonrepeated strings

Probed Position

	1	2	3	4	5	6	Mean
Repeated	93	84	84	70	74	73	79
Nonrepeated	95	84	88	65	56	70	77
Mean	94	84	86	67	65	72	78

(b) ANOVA on arcsine transformation of percentage correct

Source of variance	degrees of freedom	F	P
F (familiarity)	1,3	2.62	-
P (position)	5,15	9.22	< .001
F x P	5,15	< 1	-

Table 9

Results of forced-choice recognition task

Subject	Repeated String	Confusion Error	Number of letters in common
LT	KDNBFJ	NKDFJN[a]	5
DK	DFKBJN	GDHMNF	4
	NJGMFP	FNMCPG	5
SB	JDBFNK	NDKFCB	5
	LBCKHP	GKJPLH	4
LO	GDMLHC	BFNJMP	1
	JHLMDB	FMJPBN	3

[a]the second "N" was a typographical error

differing pairs of letter strings were grouped according to how many times the pair was repeated within a session and the ordinal distance of the repeated pair from the most recently occurring identical pair. The relationship of matching time to within-block stimulus repetition is illustrated in Figure 11. There is a small (14 msec) advantage of second repetitions (i.e., third appearance of a stimulus in a trial block) over first repetitions ($F_{(1,3)} = 16.77$, $p < .05$), an effect of repeating a stimulus within five trials of another ($F_{(5,15)} = 5.79$, $p < .005$), but there is no significant interaction of the two effects ($F < 1$). The fact that RT continues to increase with increasing separation of the two repeated stimuli suggests that although the repetition effect is short-lived, it is more than response facilitation caused by immediate repetition. The RT advantage of second over first repetitions is 22 msec smaller for repeated than for nonrepeated strings ($F_{(1,3)} = 102.78$, $p < .005$). The effect of a repetition within the succeeding five trials is also smaller (64 msec) for repeated than nonrepeated stimuli ($F_{(5,15)} = 3.80$, $p < .025$).

ERROR RATES

The error rates (over all RT sessions) for each S for each response type are displayed in Table 10. An ANOVA performed on the arsine transformation of the error rates of each S in each condition indicated that significantly more errors were made on differing stimuli than on letter string

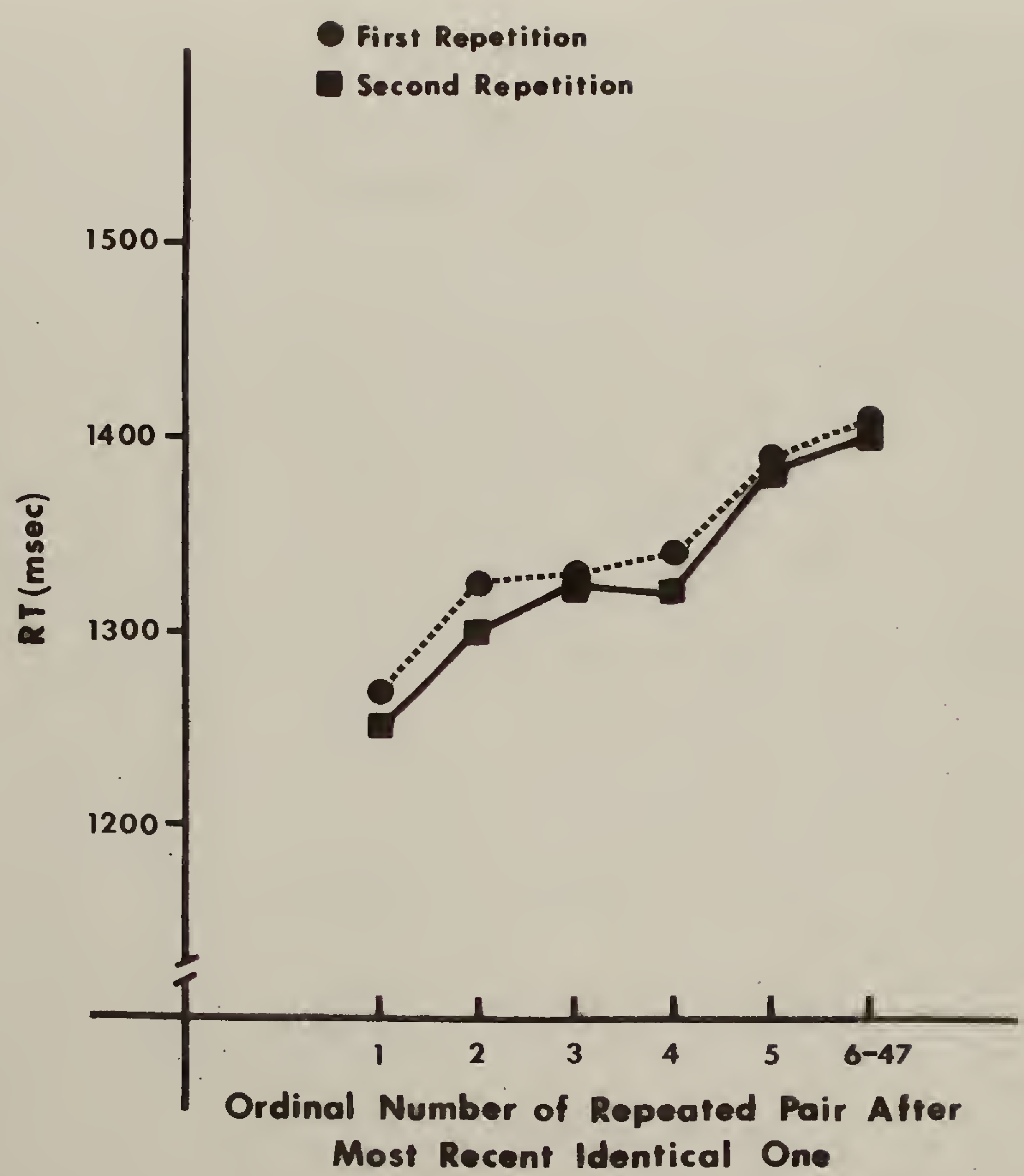

Figure 11. The relationship of matching time to within-block string repetition

Table 10

Overall error rates (in %)

Subject	% of identical stimuli incorrectly classified as DIFFERENT	% of differing stimuli incorrectly classified as SAME	Mean
LT	1.87	5.52	3.70
DK	2.46	4.69	3.58
SB	1.00	3.15	2.07
LQ	0.93	6.20	3.57
Mean	1.56	4.89	3.23

pairs which were identical ($F_{(1,3)} = 24.17$, $p < .025$).

DISCUSSION

The significant increase in the RT advantage of repeated strings indicates that some perceptual learning of the repeated letter strings occurred during the training sessions. Further, the observation that most of this advantage was retained when tested almost two months after the last training session is further evidence that the long-term repetition of specific letter strings causes a relatively permanent adaptation to those stimuli.

That such a decrease in matching time could occur in repeated letter strings whose acoustic representations are no smaller than those of nonrepeated strings (since the acoustic representations would be six letter names in both cases) strongly suggests that the advantage of words over nonwords in a perceptual comparison task is not due to the matching of the words' smaller acoustic representations. However, the present study cannot rule out the possibility that, while acoustic representations of equal size are matched, repeated perception of a stimulus allows its acoustic representation to be formed more rapidly. Smith & Spoehr (1974) have proposed that the increased speed of acoustic code formation for words is responsible for their performance advantage over nonwords. Baron (1974) demonstrated that visually differing words can be matched on the basis of sound more rapidly than pronounceable nonwords, thus indicating that when the acoustic representation is used, it can be accessed more rapidly for familiar letter strings. However, there is at least anecdotal evidence that, in the present study, acoustic representations were not used to match the letter strings. On the open-ended subject feedback form given each S after Session 20, one S (SB) wrote:

> "This effort to consciously know the different letters was slowing my reaction time so I started to sing or think of something else to take my mind off the experiment. I had some great monologue conversations and my reaction time improved because I was simply reacting to the whole letter chain ..."

Thus, it appears that at least one S was not matching acoustic representations in this task.

The close agreement of the predicted advantage of repeated strings on Session 17 with the 150 msec familiarity effect actually obtained in the new conjugates task is strong evidence that the RT advantage gained by experience with the repeated letter strings did not alter processing in only the comparison stage. The stimulus encoding processes must also have been affected.

Further, the results of the forced-choice recognition test given after Session 16 suggests that the information stored from the repeated perception of specific letter strings was not of the form which is available to willful retrieval. Several Ss remarked that if the recognition items had been presented on the display scope rather than typed on a page, their performance would have been much better. This "stimulus bound" nature of the stored information corresponds to the common observation that many people who cannot recall the correct spelling of a word can recognize the correctness or incorrectness of the spelling when they see the word. It seems that, for certain types of information, the perceptual system knows more about a word than does verbal long-term memory.

Thus, repeated visual experience with a particular letter string allows the storage of specific information about that string which facilitates its perceptual encoding. This result apparently contradicts Baron & Thurston's (1973) and Baron's (1974) finding that pronounceable nonwords (which are novel visual stimuli) can be perceived as rapidly as words (which have been seen many times). It also seems to contradict Broadbent's (1967) conclusion that there are no perceptual differences between frequently experienced words and rarely occurring ones. However, a contradiction exists only if one assumes that the perceptual facilitation to repeated strings of consonants demonstrated in the present study would also occur for common words similarly repeated. The interaction between the short-term effects of repetition found in this study with the more permanent repetition effects raises questions about the validity of such an assumption. The interaction itself indicates that both forms of repetitions act on the same perceptual processes. The nature of the interaction, that the short-term effects were smaller for strings which had been subject to more long-term repetition, suggests that the effects of repetition are reduced for stimuli which are already very familiar. On the other hand, Krueger (1970b) found no reliable differences in the effect of short-term repetition on search time through word and nonword displays. In general, the nature of the relationship between long- and short-term repetition effects is as yet unclear, and is an important area for future investigation.

Several studies (Gibson, Bishop, Schiff, & Smith, 1964; Egeth & Blecker, 1971; Henderson, 1974) have provided evidence that acronyms as well as words can be perceived more rapidly than random letter strings. Since acronyms rarely conform to the general rules of English orthography, their perceptual advantage must have been caused by long-term visual experience with those specific letter strings. The results of the present study are in strong agreement with this conclusion.

Several aspects of the present data provide clues as to what specific information is taken from repeated experience with a letter string which allows it to be matched more rapidly. Three lines of evidence indicate that information about visual features larger than single letters (e.g., shape information) did not play an important role in the perceptual learning of the letter strings. The first piece of evidence is that despite the large increase in RT caused by presenting the letter strings vertically, there was no significant decrease in the familiarity effect when the between-letter features were altered in this way. However, there was a 48 msec decrease in the familiarity effect, and it could be argued that the present study lacked the statistical power to detect this reasonably large decrease. This criticism is supported by the results of an earlier study (Schindler, Well, & Pollatsek, 1973) in which the decrease in the WSE due to vertical presentation was found to be approximately 60 msec. However, in neither that study nor the present one, were Ss' expectancies taken into account. It is possible that the reduced advantage of vertically presented familiar letter strings was due to S not realizing that the vertically presented string was indeed familiar (cf., Schindler, Well, & Pollatsek, 1974).

The second line of evidence against the importance of between-letter features in learning to see repeated strings is that the presence of a specific letter context failed to significantly alter the relative discriminability of the members of a conjugate pair. This change in relative discriminability would be probable if perceptual learning caused larger visual features to be used in place of the features of individual letters; in general the discriminability of any two sets of letter features should not be the same as that of two sets of features which span single letters. However, again, although the correlation of pair discriminability in repeated and nonrepeated strings was large, it could be argued that a more powerful study could detect some effects of constant context on letter pair discriminability.

The third line of evidence against the importance of between-letter features in the repeated string advantage is that the serial position curves for the DIFFERENT responses indicated that Ss scanned the letter strings in a left-to-right fashion.[8] If between-letter features were used, those features could not have been much larger than single letters and still be consistent with the data suggesting a serial self-terminating scan. However, as mentioned above, the serial position data are also consistent with a two-process matching strategy where some of the matches (especially those where the difference occurs at the first or last position) are made without scanning the letter string. Although between-letter features could very well have been used in this "wholistic" process, it is unlikely that those features were involved in the perceptual learning. The lack of a familiarity effect at position 1 suggests that position 1 matches in the repeated strings were made using the same kinds of features used in making position 1 matches in nonrepeated strings. Since many of the position 1 matches were presumably made by the wholistic process, it is unlikely that the features used by the wholistic process were characteristic of only the perceptually learned letter strings.

If it is unlikely that the use of features larger than single letters was responsible for the perceptual learning of the repeated letter strings, then specific information concerning the order of letters, or of features smaller than letters, must have been stored. The sets of repeated strings were constructed so that knowing any one letter and its position in a string predicted with high probability of all of the letters in that repeated string. However, the failure to find a significant familiarity effect for matches where the difference occurred at the first or second positions suggests that not all of the redundancy present in the repeated strings was used. If it is assumed that Ss scanned the display from left-to-right, then the data suggest that the predictability of the repeated strings was not used perceptually until the third position. In other words, Ss were unable to use information about which letter would follow the first, but knowing the first two letters, specific information facilitated their perception of the third. This tentative conclusion is in agreement with the finding of Colegate & Eriksen (1972) that learned trigrams in which the first two letters predicted the third could be more accurately reported from a brief exposure than could trigrams in which the first letter predicted the second.

The results of the transfer task on Session 19 indicate that not only sequential information, but also specific information about the relative position in the string of the letters (or the within-letter features) was used to facilitate perception of the repeated strings. Kolers (1970) proposed the existence of a separate mechanism responsible for ordering the perceived elements of a stimulus. Gibson (1969, p. 143) reported research which implies that an early stage of perceptual learning involves storing information about which elements occur together, and a later stage involves the storage of information about the position of the elements in the group. If there are indeed such stages of perceptual learning, then it could be that the confusion errors made by three of the Ss in the forced-choice recognition test reflect incomplete perceptual learning of one or two of the repeated strings.

The present view that sequential probability and relative position information is stored in the perceptual learning of letter strings is very close to the spelling pattern hypothesis advanced by Gibson (1969). However, while Gibson was mute on the issue of the generality of the rules governing the clustering of letters and the legal position of the clusters, the present study indicates that sequential and positional information which is specific to a single letter string can be stored, and such information can be used to speed the perception of that string.

A persistent problem in word perception involves how stored information about familiar letter strings is retrieved (Smith & Spoehr (1974) have termed this "the parsing problem"). Since stored perceptual information must be retrieved before the relevant stimulus is fully perceived, there are only two general possibilities for retrieval. The first is that the context in which the stimulus is embedded provides the cues for the retrieval of stored perceptual information. In other words, contextual cues may bias the perceptual system to "expect" stimuli from a certain group, and therefore, a stimulus from that group would be seen faster. The other possibility is that the parts of the stimulus which are perceived first serve as cues for the retrieval of stored information which can facilitate perception of the remainder of that stimulus. Smith & Spoehr's (1974) Vocalic Center Group model of word perception could be considered an example of the contextual cues position since it is the knowledge that letter strings are going to be presented which enables the accessing of the "parsing rules". On the other hand, Krueger's (1973) Schematic Processor model represents the view that it is the first-perceived parts of the stimulus which serve as the perceptual retrieval cues. Although both kinds of cues may be used, the present failure to find an effect of string familiarity on the perception of the first two positions of a six-letter string suggest that cues from the first-perceived parts of the stimulus may be more important than contextual ones for the retrieval of stored perceptual information.

Thus, a description of the perceptual processing of a letter string can be constructed from the present data. Although there are other models which are also consistent with the data, the one presented could be considered a summary of findings, and serves to illustrate the issues which are most in need of further study.

When a letter string is presented, S attends first to the leftmost visual features. The identification of the first two letters leads to the accessing of information concerning which letters will most probably occur in the third position if the already perceived letters are in positions 1 and 2. The perceptual system tests first for the features of the most probable third letter, so if it is actually there, it is identified very rapidly. The identification of the third letter may then access information about which fourth letter is most likely to follow the previous three letters. However, fifth and sixth order letter probabilities are not stored. Instead, information is stored concerning which letters are most likely to follow the last three seen conditional upon those letters being in positions 2-4 (or 3-5) of a six-letter string. The retrieval of such position-dependent letter cluster information thus is capable of speeding the perception of the fifth and sixth letters of the string.

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Footnotes

1. Several authors (e.g., Smith & Spoehr, 1974; Rubenstein, Lewis, & Rubenstein, 1971; Meyer, Schvaneveldt, & Ruddy, 1974) have proposed that acoustic encoding of a visually presented letter string is necessary for it to be perceived. However, the studies of Rubenstein et al. and Meyer et al. did not require that S match the visual features of a pair of letter strings, but rather required S to decide whether or not a letter string was a word. Since it is probable that the stimulus encoding process depends on the task, it is unclear whether the conclusions drawn from lexical decision tasks can be generalized to visual matching tasks.

2. In addition, Gibson (1971) suggested that Krueger's results may have been influenced by the fact that some of the acoustically similar letters he used were also visually similar (e.g., C and G, M and N).

3. To check this assumption, Ss were run in a probe recognition task (see Reicher, 1969) on Session 21 of this study.

4. This procedure of randomly assigning conditions to the individual trials in a block resulted in there being an unequal number of trials used to compute the means for the data analyses.

5. In all RT analyses, only correct responses were used. Also, 76 (.05%) correct RTs were discarded because they were either under 300 msec or over 3000 msec.

6. Half of the Session 19 data were lost due to E's error. The specific trial blocks which were lost can be seen in Table 3.

7. There was also no significant RT difference between mixed and separated trial blocks ($t_{(3)} = 1.30$, $p > .20$).

8. The presentation of the fixation point between the third and fourth positions and the equating of the probability of a difference appearing at any one position could not have served to encourage Ss to use a left-to-right scan. It is more likely that they simply found such a procedure to be the most efficient for the task.

Appendices

Appendix I

Instructions to subjects

This experiment is designed to investigate the effects of practice on the speed of visual perception. It is assumed that the amount of time necessary to match two stimuli is closely related to the amount of time it takes to perceive them. Thus, by measuring how long you need to correctly judge whether or not two strings of letters are identical, we will be able to estimate how long it takes you to see them.

When the word "READY?" appears on the oscilloscipe screen, you should sit up, place your forefingers lightly over the outer keys on the response console, and prepare yourself to pay close attention to the screen. When you are ready to begin, press any key.

Each trial will begin with the appearance of a "+" on the screen. This will serve as a warning signal and will tell you where to focus your gaze. Then two strings of letters will appear simultaneously on the screen, in a horizontal position with one string directly above the other. You must determine, as quickly as you can, whether or not the two strings of letters are identical or not. If the letter strings <u>are</u> identical, press the left key; if they are <u>not</u> identical, press the right key.

Although the two strings of letters will remain on the screen until you make a response, it is very important that you make the correct response as quickly as you can.

All of the letter strings will be six letters long. When two strings differ, they will differ by only one letter. It will be randomly decided whether a particular pair of strings will be the same or different, but on the average, half of the pairs will differ and half will be the same. After each correct response you make, your response time, in milliseconds, will appear in the lower left-hand portion of the screen. If you make an incorrect response, the word

"ERROR" will appear on the screen and will remain there until you press the middle key. This will give you the opportunity to rest briefly and/or reorient yourself after an error. If there are any problems during the experiment, say something -- you will be heard over the intercom.

The trials will be grouped into blocks of 48. Some of the trial blocks will use letter strings which have been shown before, while other blocks will use new letter strings. On one day, the letter strings will be presented in vertical columns rather than in horizontal rows. Each trial block will end when "END OF BLOCK" appears on the screen. At that point, you may relax until the next "READY?" is displayed.

The experiment will continue for twenty consecutive weekdays, and it is essential that you do not miss even one day. Each session will begin with a short practice block consisting of pairs of digit strings. Then you will receive four trial blocks of the letter strings.

Although we want you to make your responses as quickly as you can, it is vitally important that your responses are the <u>correct</u> ones. If you make more than a very occasional error, then you are responding too quickly. But if you never make <u>any</u> errors, then you are probably taking more time than you absolutely require. YOU SHOULD TAKE AS MUCH TIME AS YOU NEED TO RESPOND CORRECTLY, BUT NO MORE.

Any questions?

Appendix II

Results of analyses of training session

data with half-sessions variable

Source of variance	Degrees of freedom	f	p
Analysis of variance			
D (session)	15,45	16.08	< .001
H (half-session)	1,3	3.37	-
R (response)	1,3	8.50	-
F (familiarity)	1,3	76.22	< .005
DxH	15,45	1.82	-
DxR	15,45	1.08	-
HxR	1,3	< 1	-
DxF	15,45	1.54	-
HxF	1,3	< 1	-
RxF	1,3	48.75	< .01
DxHxR	15,45	< 1	-
DxHxF	15,45	1.48	-
DxRxF	15,45	< 1	-
HxRxF	1,3	34.14	< .01
DxHxRxF	15,45	< 1	-
Linear trend analysis			
D_{lin}	1,3	219.85	< .001
FxD_{lin}	1,3	10.91	< .05
RxD_{lin}	1,3	8.49	-
HxD_{lin}	1,3	3.99	-
$FxRxD_{lin}$	1,3	2.76	-
$FxHxD_{lin}$	1,3	< 1	-
$RxHxD_{lin}$	1,3	< 1	-
$FxRxHxD_{lin}$	1,3	< 1	-

Appendix III

Mean RTs for training sessions

(R = repeated, N = nonrepeated)

Subject	Response	Familiarity	Day 1	2	3	4	5
LT	Same	R	1475	1472	1314	1300	1183
		N	1597	1443	1467	1421	1395
	Different	R	1447	1397	1289	1327	1179
		N	1457	1340	1404	1310	1279
DK	Same	R	1192	1395	1341	1379	1125
		N	1287	1504	1596	1452	1365
	Different	R	1126	1172	1127	1182	1155
		N	1101	1180	1218	1211	1056
SB	Same	R	2081	1754	1609	1672	1436
		N	2159	1789	1794	1705	1619
	Different	R	1639	1489	1278	1301	1082
		N	1589	1263	1294	1359	1284
LQ	Same	R	1812	2075	1996	1851	1857
		N	1974	1985	1923	1765	1897
	Different	R	1502	1640	1718	1586	1524
		N	1837	1824	1641	1582	1647

Appendix III (cont.)

Day										
6	7	8	9	10	11	12	13	14	15	16
1323	1145	1150	1070	1078	857	1023	914	953	866	831
1173	1354	1231	1214	1175	1130	1145	1165	1195	1177	999
1300	1086	1163	1075	1052	945	1103	899	966	831	884
1212	1167	1160	1144	1135	1021	992	1066	1152	1006	885
1220	1114	1021	1045	1013	728	807	709	797	916	863
1370	1226	1240	1299	1116	970	949	888	1129	1240	1012
1071	1004	885	1017	917	798	740	711	751	885	820
1061	1045	900	1077	916	870	926	755	885	928	841
1594	1376	1512	1346	1519	1529	1428	1345	1359	1330	1410
1706	1590	1596	1713	1823	1584	1680	1542	1582	1532	1544
1236	1130	1098	997	1024	1054	1030	981	1101	1148	1111
1330	1274	1131	1164	1158	1285	1217	1175	1230	1076	1139
1960	1579	1606	1581	1582	1501	1470	1450	1453	1463	1494
2136	1870	1753	1569	1611	1654	1600	1640	1676	1679	1630
1625	1594	1419	1553	1494	1359	1273	1382	1293	1343	1344
1684	1594	1293	1341	1517	1396	1324	1438	1419	1414	1257

Appendix IV

Results of analysis of training session data collapsed over half-sessions.

Analysis of variance

Source of variance	degrees of freedom	F	p
D (session	15,45	16.67	< .001
R (response)	1,3	7.93	–
F (familiarity)	1,3	66.08	< .005
DxR	15,45	1.10	–
DxF	15,45	1.97	< .05
RxF	1,3	40.45	< .01
DxRxF	15,45	< 1	–

Linear trend analysis

D_{lin}	1,3	189.98	< .001
$F \times D_{lin}$	1,3	17.06	< .05
$R \times D_{lin}$	1,3	8.85	–
$F \times R \times D_{lin}$	1,3	2.41	–

Appendix V

Mean RTs for DIFFERENT responses during training session.

(R = repeated, N = nonrepeated)

Subject	Session group	Half-session	Familiarity	Position 1	2	3	4	5	6
LT	1-8	1	R	780	1135	1252	1429	1521	1557
			N	814	1088	1251	1478	1661	1536
		2	R	794	1010	1257	1452	1652	1539
			N	780	1176	1323	1490	1528	1535
	9-16	1	R	647	972	971	1008	1067	1059
			N	646	1119	1037	1246	1219	1122
		2	R	680	911	1099	965	1179	1077
			N	704	887	1006	1219	1173	1242
DK	1-8	1	R	642	983	997	1132	1382	1269
			N	697	922	1061	1367	1458	1473
		2	R	681	963	1160	1181	1295	1333
			N	633	860	1099	1254	1400	1417
	9-16	1	R	544	678	778	908	980	896
			N	558	720	911	1021	1154	1172
		2	R	560	713	808	920	1050	1080
			N	568	705	903	1050	1117	1083
SE	1-8	1	R	770	980	1108	1450	1607	1871
			N	760	958	987	1506	1667	1734
		2	R	765	1015	1245	1380	1694	1748
			N	748	1138	1192	1412	1737	1799
	9-16	1	R	748	821	848	1074	1323	1320
			N	708	1021	987	1242	1440	1676
		2	R	798	899	915	1158	1348	1433
			N	732	891	1026	1313	1590	1729
LQ	1-8	1	R	890	1550	1520	1706	1804	1812
			N	997	1538	1599	1723	1968	1922
		2	R	949	1419	1670	1719	1799	1984
			N	1009	1411	1624	1959	2057	2043
	9-16	1	R	813	1150	1221	1522	1650	1716
			N	862	1139	1288	1601	1715	1883
		2	R	885	1183	1226	1582	1821	1819
			N	909	1132	1336	1693	1727	1836

Appendix VI

Results of analysis of variance on DIFFERENT

RTs for training sessions

Source of variance	degrees of freedom	F	p
D (session)	1,3	105.20	< .005
H (half-session)	1,3	4.99	-
F (familiarity)	1,3	464.96	< .001
P (position of difference)	5,15	46.68	< .001
DxH	1,3	3.30	-
DxF	1,3	1.79	-
HxF	1,3	1.93	-
DxP	5,15	3.22	< .05
HxP	5,15	3.35	< .05
FxP	5,15	5.63	< .005
DxHxF	1,3	4.29	-
DxHxP	5,15	1.00	-
DxFxP	5,15	1.41	-
HxFxP	5,15	< 1	-
DxHxFxP	5,15	< 1	-